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Partitioning of energy in pregnant beef cows during nutritionally induced body weight fluctuation[1,2]

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ABSTRACT: The purpose of this study was to determine if the efficiency of energy retention in pregnant cows was dependent on the time during the pregnancy that feed was offered. Our hypothesis was that restricting feed intake during the second trimester of gestation and providing the saved feed during the third trimester was less energetically efficient than providing the feed during the second trimester. Twenty cows (4 breed composite: 1/4 Hereford, 1/4 Angus, 1/4 Red Poll, and 1/4 Pinzgauer) that had produced 1 calf before the study were fed a diet that consisted of (DM basis) 67.3% chopped corn silage, 27.0% alfalfa hay, 5.5% corn, and 0.2% NaCl. When the cows were 87 ± 0.6 d pregnant, the first nutrient balance measurement was conducted. Six subsequent nutrient balance measurements were taken on d 122 ± 0.6, 143 ± 0.6, 171 ± 0.6, 206 ± 0.6, 241 ± 0.6, and 262 ± 0.6 of gestation. Each nutrient balance measurement consisted of a 96-h total collection of feces and urine and a 24-h indirect calorimetry measurement. Ten cows were fed for moderate BW gain during the entire pregnancy, and 10 cows were feed-restricted in the second trimester and realimented during the third trimester (low-high, L-H). The BW of the cows at parturition (559 ± 14 kg) did not differ between treatments ($P = 0.20$). There was a general trend for the proportion of ME intake retained to decrease in moderate cows as pregnancy progressed. The proportion of ME intake retained in L-H cows decreased during the first 49 d of feed restriction, but the proportion of ME retained after 77 d of restriction was greater than that retained at 49 d of restriction. During realimentation, there were no time effects for efficiency of ME conversion to retained energy, but efficiency was greater for L-H cows than moderate cows ($P < 0.001$). The ability of the cow to adapt its energy metabolism during periods of moderate feed restriction and realimentation allows development of management strategies that alter the time interval of the production cycle during which supplemental feed is offered. Total savings in feed offered during the production year are minimal, but management strategies can be developed that shift which feed resources are being used.

Key words: cow, energy, heat production

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INTRODUCTION

Nutrient requirements of beef cows vary through the year, and energetic requirements of cows increase during pregnancy. The greatest requirement is during late pregnancy and early to middle lactation. Nutrient availability of grazed forages fluctuates in temperate environments. Frequently, nutrient availability is at its lowest during pregnancy. Because of the difference in nutrients available and nutrients required, cows lose body tissue to support conceptus growth. It is a common practice to supplement grazed forages with harvested feed during pregnancy to prevent the cow from losing body tissues. There are energetic costs associated with both the synthesis and catabolism of body tissues, and it has been assumed that maintaining the BW of a cow with supplemented feed is more energetically efficient than allowing it to catabolize body tissue and then resynthesize the tissue. In our earlier study with nonpregnant, nonlactating cows (Freetly and Nienaber, 1998), we concluded the efficiency of energy retention in cows that were feed-restricted, followed by realimentation, did not differ from cows fed to maintain energy balance. The results of the study with nonpregnant, nonlactating cows suggest that the time that feed resources are offered can be altered by allowing cows to catabolize tissues and regain the tissue at a later date. This lack

[1]Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

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of difference in overall energetic efficiency between the 2 feeding strategies allows for flexibility in managing grazed and harvested feed resources. Our hypothesis was that restricting feed intake during the second trimester of gestation and providing the saved feed during the third trimester was less energetically efficient than providing the feed during the second trimester.

MATERIALS AND METHODS

The US Meat Animal Research Center Animal Care and Use Committee approved these experimental procedures.

Twenty-eight cows (MARC III; 4-breed composite: 1/4 Hereford, 1/4 Angus, 1/4 Red Poll, and 1/4 Pinzgauer) that had 1 calf before study were trained for use in nutrient balance studies. Cows were bred to a single MARC III bull by natural service. Breeding dates were established using a combination of visual detection and mount detectors (Kamar, Steamboat Springs, CO). Cows were palpated 70 d after breeding, and 20 pregnant cows with similar breeding dates were selected for the study. Cows were stratified by breeding date, and 10 cows were allocated to each treatment so that breeding dates were similarly represented in each treatment. Cows were fed a diet that consisted of (DM basis) 67.3% chopped corn silage, 27.0% alfalfa hay, 5.5% corn, and 0.2% NaCl. The ration contained 1.81% N (LECO CN-2000 C-N analyzer, Saint Joseph, MI) and had a GE of 4,419 cal/g. Daily DMI (kg/d) was the sum of DM allocated for maintenance (**DM_m**, kg/d) and DM allocated for pregnancy (**DM_p**, kg/d). The value for DM_m was a function of metabolic body size (**MBS**, $kg^{0.75}$ of BW) adjusted for a BCS (1 through 9 scale) of 5.5 and a constant A that varied with treatment:

$$DM_m = A \times MBS. \qquad [1]$$

The MBS was calculated at palpation as BW plus 45 kg for every BCS under 5.5 or BW minus 45 kg for every BCS over 5.5 (NRC, 1996) raised to the 3/4 power. Before nutritional treatments were imposed, the coefficient A in Eq. [1] was set at 0.0565 kg/MBS and was kept at this value for all cows during the first balance measurement. Based on a tabular, calculated, dietary ME density of 2.39 Mcal/kg, this feeding level would provide 0.135 Mcal of ME/MBS, which is approximately the maintenance requirement for this type of cow in confinement (Freetly and Nienaber, 1998). The coefficient remained at 0.0565 kg/MBS for cows on the moderate treatment (moderate). The coefficient for the low-high (L-H) cows was decreased to 0.0418 kg/MBS on d 95 ± 0.6 of gestation for 84 d and then increased to 0.0711 kg/MBS on d 179 ± 0.6 of gestation for 84 d.

The allocation for DM_p was calculated as a function of days pregnant (t) by using the equation in the NRC (1996) that predicts ME required for conceptus growth and assumes a birth weight of 44.5 kg and a calculated dietary ME density of 2.39 Mcal/kg:

$$DM_p = \{[44.5(0.4504 - 0.000766t)e^{[(0.03233-0.0000275t)t]}]/1{,}000\}/2.39. \qquad [2]$$

Four or 5 cows were kept in each pen (493 m^2), and cows were fed individually by use of electronic headgates (American Calan Inc., Northwood, NH).

When the cows were 87 ± 0.6 d pregnant, the first nutrient balance measurement was conducted, which consisted of a 96-h total collection of feces and urine and a 24-h indirect calorimetry measurement, as described by Freetly et al. (2006b). Six subsequent nutrient balance measurements were taken on d 122 ± 0.6, 143 ± 0.6, 171 ± 0.6, 206 ± 0.6, 241 ± 0.6, and 262 ± 0.6 of gestation, for a total of 7 collection periods. The study was divided into 2 phases for analysis. Phase 1 consisted of the initial measurement taken before feed restriction (87 ± 0.6 d pregnant) and those taken during the 84 d of reduced feed (122, 143, and 171 ± 0.6 d of pregnancy), and phase 2 consisted of measurements taken during the 84-d realimentation (206, 241, and 262 ± 0.6 d of pregnancy).

Nutrient Balance Calculations

Metabolizable energy (Mcal), retained energy (Mcal), and retained N intake (g) were calculated by difference. Energy retained as protein was estimated assuming a N content of 17% for meat protein and a caloric content of 5.7 Mcal/kg of protein (Kleiber, 1975). The equations used were as follows:

$$\text{ME intake } (ME_i) = \text{intake energy} - \text{fecal energy} - \text{urinary energy} - \text{gaseous energy}; \qquad [3]$$

$$\text{Retained energy (RE)} = ME_i - \text{heat energy}; \qquad [4]$$

$$\text{Retained N (RN)} = \text{intake N} - \text{fecal N} - \text{urinary N}; \qquad [5]$$

$$\text{Tissue energy retained as protein (RPE)} = \text{RN} \times 5.88 \text{ g of protein/g of N} \times 5.7 \text{ kcal/g of protein; and} \qquad [6]$$

$$\text{Tissue energy retained as fat and carbohydrate} = \text{RE} - \text{RPE}. \qquad [7]$$

Cumulative energy and protein retained during the restriction and realimentation were estimated by fitting the greatest level polynomial to each response variable (n observations – 1) and then integrating the area under the curve. For the purpose of fitting the polynomials, retained energy and N at –7 d were assumed to be equal to those that would have been measured at time 0. The polynomial for cows in the moderate group was fit for the entire 168 d that the cows were on the study. For phase 1, the curves were integrated from 0 through 84 d, and for phase 2, the curves were integrated from d 85 through 168. For cows in the L-H treatment, a separate polynomial was fitted for each phase. Like the moderate cows, retained energy and N at −7 d for L-H cows were assumed to be equal to those that would have been measured at time 0. It was also assumed that balance measurements taken on d 77 through 81 were equal to those that would have been observed at 84 d of feed restriction. This latter assumption is based on our earlier study of time for adaptation during feed restriction (Freetly et al., 2006a). Cumulative retention during phase 1 for L-H cows was then calculated by integrating the polynomial that was fitted from d 0 through 84 of the study. For phase 2, it was assumed that the energy retention rate adapted immediately and that balance measurements taken 28 d after realimentation were a reasonable estimate of the balance measurement taken at time 0 of realimentation. This assumption is based on our earlier studies of adaptation to realimentation (Freetly et al., 2006a) and may represent a slight overprediction of energy retention during the first 7 d. Cumulative retention of L-H cows in phase 2 was estimated by integrating the polynomial that was fit from d 0 through 84 of realimentation.

Maternal BW was calculated as the difference between BW and estimated weight of the gravid uterus. The gravid uterine weight was calculated using the equation developed by Ferrell et al. (1976a).

Statistical Analyses

Treatment and period effects were analyzed as repeated measures using the MIXED procedure (SAS Inst. Inc., Cary, NC) with a covariance structure of compound symmetry and a Satterthwaite degrees of freedom method. The model included repeated measures for animal nested within treatment, treatment, period, and treatment × period. Least squares means and SEM are presented in Tables 1 and 2. Data collected during feed restriction (phase 1) and data collected during realimentation (phase 2) were analyzed as 2 separate data sets.

Treatment differences for calf birth weight, cow parturition BW, BCS, gestation length, cumulative retained protein, and cumulative retained energy were tested with an ANOVA. Treatments were considered to differ when means tests had a $P < 0.05$.

RESULTS

The BW of cows at parturition did not differ (P = 0.20) between L-H (542 ± 21 kg) and moderate cows (577 ± 16 kg), although the pattern of BW gain was different between treatments during feed restriction (Figure 1; $P < 0.001$). During feed restriction (122 to 171 d pregnant), L-H cows gained less BW than control cows ($P < 0.001$), and cows lost maternal BW (Figure 1; $P < 0.001$). Body condition score at parturition tended to be lower ($P = 0.06$) in the L-H cows (5.2 ± 0.2) than in moderate cows (5.7 ± 0.2). Gestation length did not differ ($P = 0.49$) between moderate (285 ± 2 d) and L-H cows (286 ± 2 d). Calf birth weight did not differ (P = 0.53) between moderate (38.9 ± 1.1 kg) and L-H calves (37.9 ± 1.1 kg).

During phase 1 of the study, energy excreted in the feces and urine and energy lost as heat followed the same patterns as intake energy (Table 1). Energy released as gas decreased when intake energy decreased (Table 1; $P < 0.001$). Energy retained from period 1 through period 3 decreased ($P < 0.009$) in consecutive periods after feed restriction but increased in period 4 over period 3 ($P = 0.007$; Table 1). After realimentation in phase 2, fecal energy excretion followed the same pattern as energy intake. Fecal energy was greater in the L-H cows in periods 5 and 6 ($P < 0.001$) and tended to be greater in period 7 ($P = 0.08$; Table 2). Urinary and gaseous energy ($P < 0.001$) release increased with time, but they did not differ between treatments ($P >$ 0.18; Table 2). The L-H cows retained more energy (P < 0.001) than moderate cows, and energy retained increased with time ($P = 0.02$; Table 2). There was a general trend for the proportion of ME intake retained to decrease in moderate cows as pregnancy progressed (Tables 1 and 2). The proportion of ME intake retained in L-H cows decreased consecutively from period 1 through period 3 ($P < 0.001$), but the proportion of ME retained in period 4 was greater than that retained in period 3 ($P = 0.002$). During realimentation, efficiency was greater for L-H cows (Table 2; $P < 0.001$).

The L-H cows weighed 32 kg less (Table 1) at the beginning of the study and, consequently by design, they had a lower DMI over the total 168 d ($P < 0.01$; Figure 2). The retained energy did not differ between treatments ($P = 0.33$; Figure 3). The fraction of energy retained as protein differed between treatments within phases ($P < 0.001$), but energy retained as protein across the entire feeding period did not differ between treatments ($P = 0.79$; Figure 4).

DISCUSSION

The gross efficiency of conversion of ME to retained energy decreased in the moderate cows as pregnancy progressed. The decreased efficiency in ME retained during pregnancy is associated with an increase in heat production as pregnancy progresses (Ritzman and Benedict, 1938). As observed in our study, this increase is most rapid during the third trimester of gestation. The increase in heat production is a combination of heat produced to maintain maternal tissues and the heat released during accretion of maternal and conceptus tissue. The rise in heat production and decrease in efficiency of ME retention have been attributed to an increase in maintenance requirements and a low efficiency of energy accretion in conceptus tissues (Moe and Tyrrell, 1972). Although the overall decrease in efficiency of ME retention in tissues has been well documented, assigning the causal effects have been more difficult partially because of the mathematical algo-

Table 1. Energy metabolism of pregnant cows during feed restriction

	Period and days restricted								*P*-values		
	1 (–7 to –4)		2 (28 to 31)		3 (49 to 52)		4 (77 to 80)				
Item	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Treatment (T)	Period (P)	T × P
Pregnant, d	87	0.6	122	0.6	143	0.6	171	0.6	—	—	—
BW, kg									0.02	<0.001	<0.001
Moderate	518	14	529	14	543	14	561	14			
Low-high	486	14	479	14	486	14	494	14			
Intake, kcal/d									<0.001	<0.001	<0.001
Moderate	28,623	510	30,390	510	30,571	510	31,511	512			
Low-high	27,296	510	21,721	510	22,025	512	23,106	510			
Fecal, kcal/d									<0.001	<0.001	<0.001
Moderate	10,141	281	10,824	281	12,022	281	12,003	286			
Low-high	9,488	281	7,150	281	8,184	286	8,380	281			
Urine, kcal/d									<0.001	<0.001	<0.001
Moderate	823	23	815	23	763	23	798	23			
Low-high	811	23	640	23	635	23	679	23			
Gas, kcal/d									<0.001	<0.001	<0.001
Moderate	1,913	61	1,874	61	1,888	61	1,911	63			
Low-high	1,901	61	1,589	61	1,543	63	1,437	61			
Heat, kcal/d									<0.001	<0.001	<0.001
Moderate	13,581	344	14,438	344	14,700	344	15,182	346			
Low-high	13,150	344	11,735	344	11,710	346	11,972	344			
Retained, kcal/d									0.001	<0.001	<0.001
Moderate	2,166	244	2,440	244	1,198	244	1,619	252			
Low-high	1,946	244	607	244	–56	251	637	244			
Efficiency, RE/ME[1]									0.009	<0.001	0.001
Moderate	0.138	0.017	0.144	0.017	0.076	0.017	0.096	0.017			
Low-high	0.129	0.017	0.049	0.017	–0.005	0.017	0.048	0.017			

[1]RE = retained energy.

Table 2. Energy metabolism of pregnant cows during feed realimentation

	Period and days realimented						P-values		
	5 (28 to 31)		6 (63 to 66)		7 (84 to 87)				
Item	Mean	SEM	Mean	SEM	Mean	SEM	Treatment (T)	Period (P)	T × P
Pregnant, d	206	0.6	241	0.6	262	0.6	—	—	—
BW, kg							0.10	0.002	0.19
Moderate	580	15	586	15	609	15			
Low-high	537	15	570	15	568	15			
Intake, kcal/d							<0.001	<0.001	0.09
Moderate	35,114	825	36,617	852	41,688	825			
Low-high	40,801	825	41,409	852	44,921	825			
Fecal, kcal/d							0.002	<0.001	0.02
Moderate	14,609	504	14,433	517	16,710	504			
Low-high	17,578	504	17,048	517	17,992	504			
Urine, kcal/d							0.56	<0.001	0.44
Moderate	870	25	904	26	1,063	25			
Low-high	883	25	947	26	1,057	25			
Gas, kcal/d							0.18	<0.001	0.09
Moderate	1,927	87	2,121	90	2,526	87			
Low-high	2,208	87	2,252	90	2,537	87			
Heat, kcal/d							0.80	<0.001	0.69
Moderate	16,792	230	18,538	249	19,836	230			
Low-high	17,174	230	18,594	249	19,870	230			
Retained, kcal/d							<0.001	0.02	0.97
Moderate	916	379	507	397	1,553	379			
Low-high	2,958	379	2,536	397	3,464	379			
Efficiency, RE/ME[1]							<0.001	0.052	0.75
Moderate	0.049	0.017	0.027	0.018	0.073	0.017			
Low-high	0.145	0.017	0.119	0.018	0.148	0.017			

[1]RE = retained energy.

rithm used to describe energy metabolism. Underestimating maintenance cost results in underpredicting efficiency of ME conversion to tissue. Based on the oxygen consumption of the gravid uterus (Reynolds et al., 1986), we can estimate that approximately 40% of the increase in heat production associated with pregnancy is due to energy expenditure by the gravid uterus. Reynolds et al. (1986) estimated that the efficiency of energy accretion of the conceptus was 15% and that of the fetus was 38%. The discrepancy in estimating the overall efficiency of ME conversion to conceptus tissues is largely a consequence of whether the increased energy expenditure of maternal tissues associated with pregnancy is assigned to the maintenance or the efficiency estimate. In ewes, metabolic fluxes across the maternal liver increase during late pregnancy (Freetly and Ferrell, 1998, 2000), and the liver accounts for 20% of the increase in energy expenditure (Freetly and Ferrell, 1997). Cardiac output increases during pregnancy (Rosenfeld, 1977), suggesting an increase in expenditure due to cardiac work. Numerous other organs most likely contribute to the increase in energy expenditure as their metabolic fluxes increase to support the gravid uterus. In addition to the increased metabolic demand associated with pregnancy, the cow is beginning to prepare for lactation. Assigning the energetic cost of accreting mammary tissue (Ferrell et al., 1976a) and its maintenance will affect our estimates of maintenance and efficiency. In our study, the majority of the energy retained can be attributed to maternal energy gain. Total energy retained was 235.2 Mcal, and we estimated 50.4 Mcal was retained in the gravid uterus (Ferrell et al., 1976a), leaving 184.8 Mcal as maternal energy gain. Total N retention was 4,192 g, and we estimated that 1,003 g of N was deposited in the gravid uterus (Ferrell et al., 1976a), leaving 3,189 g of N as maternal gain. Based on the above values, we would estimate that, of the maternal energy gain, 106.9 Mcal was protein and 77.9 Mcal was fat. Assuming an efficiency of 20% for protein energy gain and 70% for fat energy gain (Geay, 1984), our overall efficiency estimate of maternal energy gain is 41%, which is close to the 39% efficiency observed in pregnant heifers using the comparative slaughter technique (Ferrell et al., 1976b). Whether the increase in energy expenditure of maternal tissues that support pregnancy is assigned to maintenance or the efficiency estimate, the consequence of their increased energy expenditure, combined with the energy expendi-

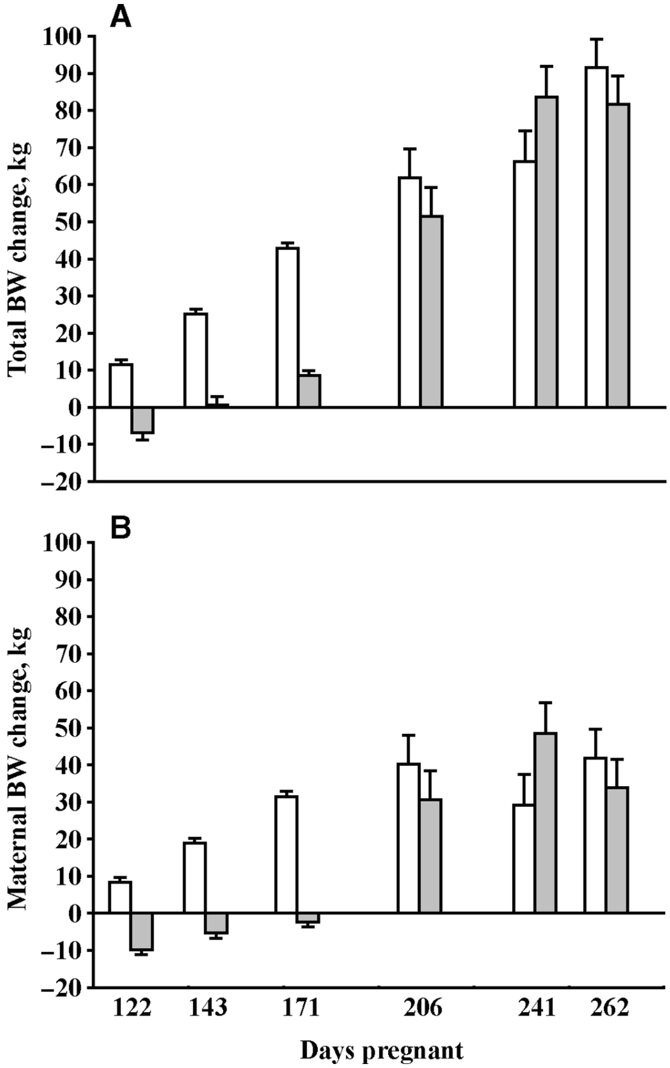

Figure 1. (A) Change in BW from initial BW (87 d of pregnancy) of cows fed for moderate (white bar) BW gain during pregnancy and for cows fed for restricted BW gain during the second trimester [treatment (T) × period (P); $P < 0.001$] and rapid BW gain during the third trimester (low-high, gray bar; P-values: T = 0.10, P = 0.002, and T × P < 0.19). (B) Change in maternal BW gain estimated as the difference between changes in BW and conceptus weight (Ferrell et al., 1976a) of moderate (white bar) and low-high (gray bar) cows during feed restriction (T × P; $P < 0.001$) and realimentation (P-values: T = 0.93; P = 0.002, and T × P < 0.13). Values are the least squares means, and error bars are SEM.

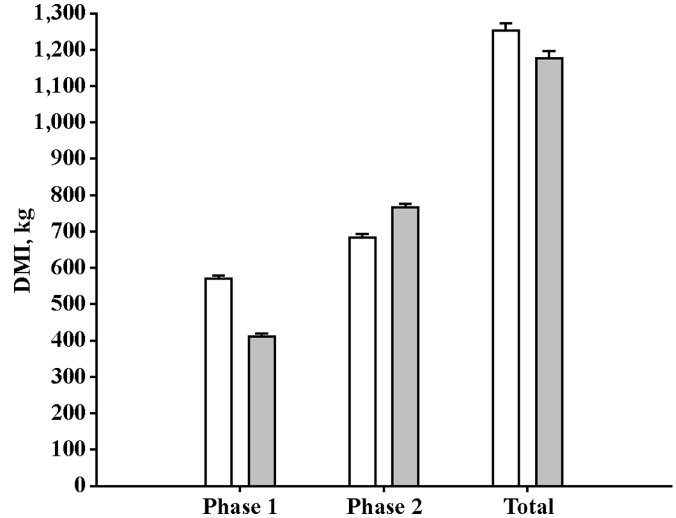

Figure 2. Cumulative DMI during phase 1 (0 through 84 d of the study; $P < 0.001$), phase 2 (85 through 168 d of the study; $P < 0.001$), and total (0 through 168 d of the study; $P = 0.01$) of moderate (white bar) and low-high (gray bar) cows. Values are the least squares means, and error bars are SEM.

ture of conceptus tissue, still results in an overall decrease in the efficiency of ME retained by the pregnant cow.

During phase 1, feed offered to the L-H cows was restricted to provide adequate ME for growth of the gravid uterus but limited ME for maternal tissue energy gain. During the feed restriction, the efficiency of ME retention decreased. We estimated that total energy retention during phase 1 for L-H cows was 40.5 Mcal and that 8.3 Mcal of the energy was retained in the gravid uterus. These low levels of retained energy combined with the fixed cost of maintaining the cow result in the low efficiency estimates. Although there is some offsetting reduction in energy expenditures during feed restriction, such as decreased visceral tissues energy expenditure (Freetly et al., 1995), many of the fixed energetic costs remain. The minor changes in BW during the feed restriction suggest that the energetic cost of maintaining BW between the treatments was similar. Because feed restriction was not severe enough to slow fetal development, the increased energy expenditure associated with the gravid uterus and the increased metabolic activity of maternal organs to support the gravid uterus remained elevated.

During the first 52 d of feed restriction, efficiency of ME retention decreased; however, during period 4, energy retained and efficiency increased compared with period 3. The increase in daily energy retention in the gravid uterus from 143 d of gestation (1.4 kcal/d) to 171 d of gestation (2.6 kcal/d) does not account for the 419 kcal/d increase in retained energy, suggesting that other mechanisms are contributing to the increase. We observed a similar pattern of adaptation in feed-restricted nonpregnant, nonlactating cows (Freetly and Nienaber, 1998), in which there was an increase in retained energy after 84 d of feed restriction. Jointly, these studies suggest a possible long-term adaptation to feed restriction, which allows the cow to be more efficient; however, unlike our earlier study, cows in this study had an increase in ME intake. The L-H cows received 951 kcal of ME/d more during period 4 than during period 3, and with an efficiency of 44% for tissue energy gain, much of the increase in energy retention

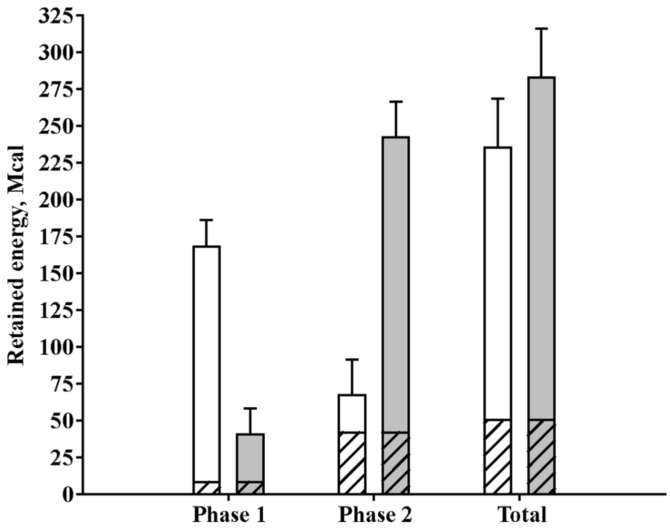

Figure 3. Cumulative retained energy during phase 1 (0 through 84 d of the study; $P < 0.001$), phase 2 (85 through 168 d of the study; $P < 0.001$), and total (0 through 168 d of the study; $P = 0.33$) of moderate (white bar) and low-high (gray bar) cows. Estimated energy retained in the gravid uterus is indicated by the striped portion of a bar. Values are the least squares means, and error bars are SEM.

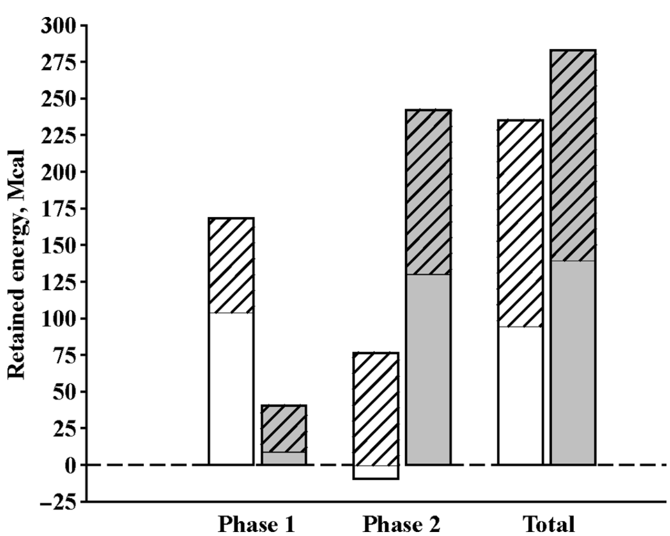

Figure 4. Cumulative energy retained as protein (striped portion of a bar) during phase 1 (0 through 84 d of study, pooled SEM = 2.9; $P < 0.001$), phase 2 (85 through 168 d of the study, pooled SEM = 5.5; $P < 0.001$), and total (0 through 168 d of the study, pooled SEM = 7.0; $P = 0.79$). Cumulative energy retained as carbohydrate and fat (open portion of a bar) during phase 1 (0 through 84 d of the study, pooled SEM = 16.2; $P < 0.001$), phase 2 (85 through 168 d of the study, pooled SEM = 21.3; $P < 0.001$), and total (0 through 168 d of the study, pooled SEM = 29.9; $P = 0.29$). Values are the least squares means for moderate (white bar) and low-high (gray bar) cows.

could be accounted for. During phase 2, efficiency of energy retention increased with the increase in feed intake. This increase in efficiency can be partially explained by the increase in ME intake relative to the fixed energetic cost; however, the efficiency with which the additional ME was converted to retained energy (84 to 98%) exceeds the expected efficiency to convert ME to tissue energy (44%). Composition of the additionally retained energy will influence the efficiency of energy retention. If all the additional retained energy was retained as fat, we would expect the efficiency to be closer to 70%. These data suggest that additional mechanisms beyond composition of the gain are contributing to the increase in efficiency of energy retained.

In the current study, cows gained the same amount of BW during the study using different patterns of BW gain. Traditionally, it has been assumed that allowing cows to lose tissue energy was an inefficient use of feed resources because of the inefficiencies associated with tissue accretion. However, our findings suggest that the ability of the cow to adapt its energy metabolism to periods of feed restriction and realimentation allows flexibility in choosing when in the production cycle to provide cows feed. Placing cows in low or negative energy balance during parts of the year will have negative effects on calf production. Cows that are in negative nutrient balance during breeding are less fertile (Bellows and Short, 1978; DeRouen et al., 1994). Nutrient restriction during the third trimester decreases calf birth weights (Freetly et al., 2005). Nutrient restriction during lactation decreases milk production and decreases calf weaning weight (Jenkins and Ferrell, 1992, 1994). The nutrient requirements of the cow are at their lowest during the second trimester of gestation after calves have been weaned. In our experiments, we found that restricting nutrient intake during the second trimester of gestation and realimenting during the third trimester was a plausible management strategy in changing timing of nutrient allocation without affecting calf production (Freetly et al., 2000, 2005). Restricting feed throughout pregnancy has long-term effects on production performance of calves. Heifers born to cows restricted during pregnancy have a lower pregnancy rate (Martin et al., 2007), and steers born to feed-restricted cows have lighter BW entering the finishing phase (Stalker et al., 2006). These studies suggest that fetal developmental programming is being mediated through nutritional environment and that management strategies that use BW cycling during pregnancy need to establish times during fetal development when calves are most sensitive to maternal nutrient environment.

This study differs from our earlier study (Freetly and Nienaber, 1998) with nonpregnant, nonlactating cows. Cows in this study remained in a positive energy balance during the restriction rather than being placed in a negative energy balance. It was our objective not to restrict energy for conceptus growth. Slaughter balance experiments using pregnant heifers that were more severely restricted than the cows in our study did not retard fetal growth rates (Ferrell et al., 1976b). The lack of a treatment effect on calf birth weight and whole-animal energy retention was greater than the energy required for conceptus retention, suggesting that fetal growth was not affected by our feed restriction.

In conclusion, the ability of the cow to adapt its energy metabolism during periods of moderate feed restriction and realimentation allows development of management strategies that alter the time interval of the production cycle during which supplemental feed is offered. In the current study, allowing cows to cycle in BW did not result in a decrease in feed fed, but management strategies can be developed that shift which feed resources are being used and when they are being used. Management strategies developed around the ability of the cow to adapt need to be mindful of how the timing and severity of restriction will affect fetal development.

LITERATURE CITED

Bellows, R. A., and R. E. Short. 1978. Effects of precalving feed level on birth weight, calving difficulty and subsequent fertility. J. Anim. Sci. 46:1522–1528.

DeRouen, S. M., D. E. Franke, D. G. Morrison, W. E. Wyatt, D. F. Coombs, T. W. White, P. E. Humes, and B. B. Greene. 1994. Prepartum body condition and weight influences on reproductive performance of first-calf beef cows. J. Anim. Sci. 72:1119–1125.

Ferrell, C. L., W. N. Garrett, and N. Hinman. 1976a. Growth, development, and composition of the udder and gravid uterus of beef heifers during pregnancy. J. Anim. Sci. 42:1477–1489.

Ferrell, C. L., W. N. Garrett, N. Hinman, and G. Grichting. 1976b. Energy utilization by pregnant and non-pregnant heifers. J. Anim. Sci. 42:937–950.

Freetly, H. C., and C. L. Ferrell. 1997. Oxygen consumption by and blood flow across the portal-drained viscera and liver of pregnant ewes. J. Anim. Sci. 75:1950–1955.

Freetly, H. C., and C. L. Ferrell. 1998. Net flux of glucose, lactate, volatile fatty acids, and nitrogen metabolites across the portal-drained viscera and liver of pregnant ewes. J. Anim. Sci. 76:3133–3145.

Freetly, H. C., and C. L. Ferrell. 2000. Net flux of nonesterified fatty acids, cholesterol, triacylglycerol, and glycerol across the portal-drained viscera and liver of pregnant ewes. J. Anim. Sci. 78:1380–1388.

Freetly, H. C., C. L. Ferrell, and T. G. Jenkins. 2000. Timing of realimentation of mature cows that were feed-restricted during pregnancy influences calf birth weights and growth rates. J. Anim. Sci. 78:2790–2796.

Freetly, H. C., C. L. Ferrell, and T. G. Jenkins. 2005. Nutritionally altering weight gain patterns of pregnant heifers and young cows changes the time that feed resources are offered without any difference in production. J. Anim. Sci. 83:916–926.

Freetly, H. C., C. L. Ferrell, T. G. Jenkins, and A. L. Goetsch. 1995. Visceral oxygen consumption during chronic feed restriction and realimentation in sheep. J. Anim. Sci. 73:843–852.

Freetly, H. C., and J. A. Nienaber. 1998. Efficiency of energy and nitrogen loss and gain in mature cows. J. Anim. Sci. 76:896–905.

Freetly, H. C., J. A. Nienaber, and T. M. Brown-Brandl. 2006a. Changes in heat production by mature cows following changes in feeding level. J. Anim. Sci. 84:1429–1438.

Freetly, H. C., J. A. Nienaber, and T. M. Brown-Brandl. 2006b. Partitioning of energy during lactation of primiparous beef cows. J. Anim. Sci. 84:2157–2162.

Geay, Y. 1984. Energy and protein utilization in growing cattle. J. Anim. Sci. 58:766–778.

Jenkins, T. G., and C. L. Ferrell. 1992. Lactation characteristics of nine breeds of cattle fed various quantities of dietary energy. J. Anim. Sci. 70:1652–1660.

Jenkins, T. G., and C. L. Ferrell. 1994. Productivity through weaning of nine breeds of cattle under varying feed availabilities. I. Initial evaluation. J. Anim. Sci. 72:2787–2797.

Kleiber, M. 1975. The Fire of Life. Robert E. Krieger Publ. Co., Huntington, NY.

Martin, J. L., K. A. Vonnahme, D. C. Adams, G. P. Lardy, and R. N. Funston. 2007. Effects of dam nutrition on growth and reproductive performance of heifer calves. J. Anim. Sci. 85:841–847.

Moe, P. W., and H. F. Tyrrell. 1972. Metabolizable energy requirements of pregnant dairy cows. J. Dairy Sci. 55:480–483.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th rev.ed. Natl. Acad. Press, Washington, DC.

Reynolds, L. P., C. L. Ferrell, D. A. Robertson, and S. P. Ford. 1986. Metabolism of the gravid uterus, fetus and utero-placenta at several stages of gestation in cows. J. Agric. Sci. Camb. 106:437–444.

Ritzman, E. G., and F. G. Benedict. 1938. Nutritional Physiology of the Adult Ruminant. Publ. 494. Carnegie Inst. Wash., Washington, DC.

Rosenfeld, C. R. 1977. Distribution of cardiac output in ovine pregnancy. Am. J. Physiol. 232:H231–H235.

Stalker, L. A., D. C. Adams, T. J. Klopfenstein, D. M. Feuz, and R. N. Funston. 2006. Effect of pre- and postpartum nutrition on reproduction in spring calving cows and calf feedlot performance. J. Anim. Sci. 84:2582–2589.